From Appleton to Arecibo and Beyond.

J. D. Mathews
Radar Space Sciences Lab, Penn State University
Arecibo Science Advocacy Partnership

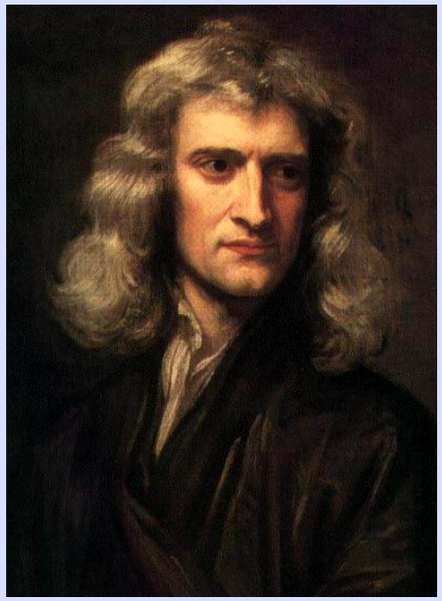
Abstract

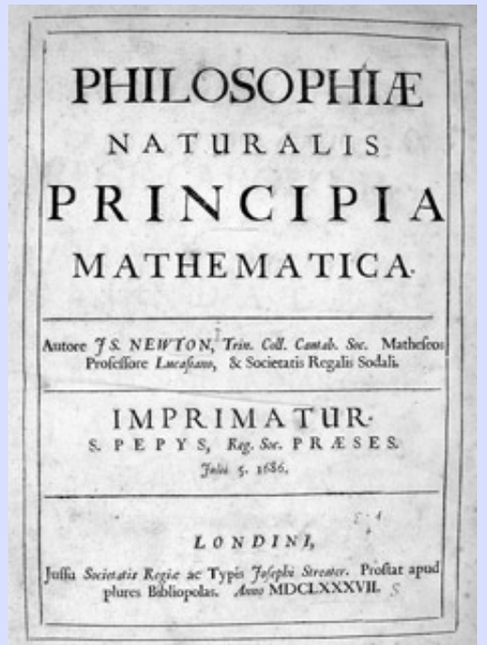
It started before Maxwell, Marconi helped it along, and Einstein gave fundamental insights. Then, what we came to call radar, was used by Appleton to directly detect the ionosphere (Kennelly-Heaviside Layer) in 1925. Further early geophysical uses of radar included the development of ionospheric sounders and the study of radar meteors. World War II led to significant advances in radar techniques including powerful RF transmitter tubes and display devices such as oscilloscopes. After WWII surplus military radar equipment and the new engineering techniques led to radio and radar astronomy with the development of the Jodrell Bank Experimental Station. With this rich and rapidly developing engineering and scientific environment we come to Arecibo Observatory (AO) at its 50th anniversary. The reasons William E. (Bill) Gordon developed the 305 m Arecibo dish are briefly reviewed. It is particularly appropriate to review the intellectual history that led to the 305 m dish and to summarize some of the innovative radar-based geophysical research that has resulted. In understanding how AO came to be and the many resulting developments that are embodied in the hundreds of PhDs and thousands of journal papers that have resulted, we look to the future of AO.

So, where does the march of science and engineering that led to Arecibo Observatory begin?

Sir Isaac Newton

25 December 1642 – 20 March 1727





PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA

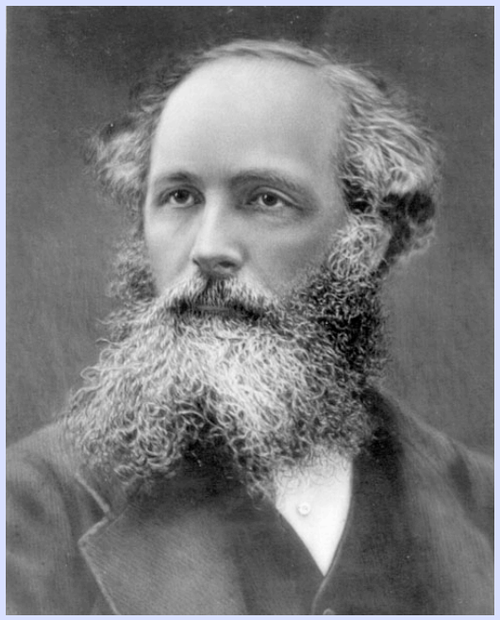
Autore *Is. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Justu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

James Clerk Maxwell

13 June 1831 – 5 November 1879



A Dynamical Theory of the Electromagnetic Field. By J. Clerk Maxwell, *F.R.S.*

Received October 27,—Read December 8, 1864.

- Part I - Introductory
- Part II - On Electromagnetic Induction
- Part III - General Equations of the Electromagnetic Field
- Part IV - Mechanical Actions in the Field
- Part V - Theory of Condensers
- Part VI - Electromagnetic Theory of Light
- Part VII - Calculation of the Coefficients of Electromagnetic Induction

- **Phil. Trans. R. Soc. Lond.** 1 January 1865 **vol. 155** 459-512, doi: **10.1098/rstl.1865.0008**

We have **F**=m**a** and the Maxwell Equations. Next we need electrons (and ions...) and, thereby, Thomson scattering from "free" electrons in the ionosphere which is what Bill Gordon (fortunately) expected to see.

Sir Joseph John Thomson

18 December 1856 – 30 August 1940

Nobel Prize in Physics 1906

would require a very full discussion of the effect of increased velocity in diminishing the effective size of atoms to be quite sure of what would happen. If we take two bodies as colliding when they come so close that their paths are deflected, say 10deg., it is quite evident that they must approach more closely in order to in this sense collide when their relative velocity is large than when it is small. The variation is enormous if the law of force be the inverse square of the distance, and charged atoms may act according to this law. If so it seems at least possible that the effective size of these rapidly moving charged atoms, both as regards one another and as regards the residual gas, may be different from that of the ordinary molecules that constitute the gas. It may also be that the laws of impacts of spheres do not apply even approximately to the actions of molecules polarised by an electric force. The action may be transmitted from molecule to molecule, not by any impact, but by the advent of a charged atom enabling one of the constituents of the molecule it is approaching to obey the electric force and dart off in the line or nearly the line of the approaching one. This would account for actions being transmitted long distances in straight lines.

An hypothesis seems also possible on the lines of Grotthus, chains being formed under the action of the cathode rays or under the action of Röntgen rays due to the impacts of cathode rays on the molecules. In fact, there seems an *embarras de richesse* in the way of possible explanations of the transparency of media to cathode rays without supposing that we are in presence of a possible method of transmutation of matter. This latter is by far the most interesting hypothesis, and it is very much to be hoped that Prof. J. J. Thomson's hypothesis is true.

As regards the calculation of the ratio of the numerical measure of the mass of the corpuscule to the electric charge it carries, there are two suggestions that can be made in respect of it. The first is that we are dealing with free electrons in these cathode rays. This is somewhat like Prof. J. J. Thomson's hypothesis, except that it does not assume the electron to be a constituent part of an atom, nor that we are dissociating atoms, nor consequently that we are on the track of the alchemists. There seems every reason to suppose that electrons can be transferred from atom to atom without at all destroying or indeed sensibly changing the characteristic properties of the atom: that in fact there is a considerable analogy between a charged sphere and an atom with an electron charge. If this be so, the question of course arises, how far can an electron jump in going from atom to atom? Why not the length of a cathode, say, or at least from molecule to molecule along it, or anyway in nearly straight lines along it? In this case, the mass calculated may be the effective mass of the electron, and that will depend on its size as an electric charge, and, as Dr. Lodge has pointed out, in the corresponding case of Zeemann's observation the resultant size is quite feasible. If it be so we should have this further interesting result. We can calculate how much nearer the electrons must be in 2HCl than in HH and ClCl if the heat of combination be due to this approach. This gives a maximum size for an electron if they preserve their individuality. Knowing the size of the electrons, *and assuming it to stay constant*, we could calculate what the change in the effective inertia of the electrons must be, due to their being nearer together in 2HCl than in $H_2 + Cl_2$. This would give us a possible reason why the mass of matter may change when it changes its chemical constitution. I have not had time to worry out the calculation, but it is evident that the change in effective inertia would be a very small part of the total inertia of the matter: yet it may be within our powers of measurement. If there is no change, then either the size of the electrons changes in such a way as to compensate exactly for their approach, a very likely contingency, or else the inertia we are dealing with is not the effective inertia of electrons.

The other suggestion is that Prof. J. J. Thomson is quite wrong in assuming that nearly all the bombarding molecules give up charges to the cylinder, or what comes to much the same thing, that he is wrong in thinking that all the charges stuck there, and that only a few of them escape into the surrounding gas. Suppose that only a thousandth part of the molecules entering the cylinder gave up charges to it, and that the rest were either uncharged or were driven out by the entering ones, and accumulated near the anode to which they quietly gave up their charges, then the energy of these 999 would be attributed to the few that give up their charges, and this naturally leads to an abnormally small mass and an extraordinarily great velocity for these molecules. The velocity that Prof. J. J. Thomson now attributes to the corpuscules in cathode rays is $1{\cdot}5 \times 10^9$cm. per second, which is only one-twentieth of that of light, a velocity that would penetrate anything, and is enormously greater than what his own direct observations of cathode rays give. This latter, when introduced into the equation—

$$\frac{m}{e}v = \mathrm{I},$$

gives values for m corresponding approximately to that usually received for the mass of an atom. Hence this recent investigation coupled with his former one would lead to the conclusion that only a small part of the projected atoms give up their charge to the cylinder, either because they take it out again with themselves, or because only a small proportion of the bombarding atoms are charged. In any case, there does not seem much necessary connection between these experiments and the case Zeemann investigates. In this latter case it would seem *most* improbable that the moving electric charge that originates the light vibrations should carry the whole atom along with it in its incursions. It would seem much more likely that an extremely minute deformation of the atom would accompany the incursions of the charge, so that Zeemann's result is what one would naturally expect, and the only remarkable thing about it seems to me to be that such a large proportion of the matter accompanies the ether incursions. In his case it may quite possibly be that the inertia is that of the electron and not of the matter at all.

In conclusion, I may express a hope that Prof. J. J. Thomson is quite right in his by no means impossible hypothesis. It would be the beginning of great advances in science, and the results it would be likely to lead to in the near future might easily eclipse most of the other great discoveries of the nineteenth century, and be a magnificent scientific contribution to this Jubilee year.

CATHODE RAYS.*

BY PROF. J. J. THOMSON, F.R.S.

The first observer to leave any record of what are now known as the Cathode Rays, seems to have been Plücker, who in 1859 observed the now well known green phosphorescence on the glass in the neighbourhood of the negative electrode. Plücker was the first physicist to make experiments on the discharge through a tube, in a state anything approaching what we should now call a high vacuum: he owed the opportunity to do this to his fellow townsman Geissler, who first made such vacua attainable. Plücker, who had made a very minute study of the effect of a magnetic field on the ordinary discharge which stretches from one terminal to the other, distinguished the discharge which produced the green phosphorescence from the ordinary discharge, by the difference in its behaviour when in a magnetic field. Plücker ascribed these phosphorescent patches to currents of electricity which went from the cathode to the walls of the tube and then for some reason or other retraced their steps.

The subject was next taken up by Plücker's pupil, Hittorf, who greatly extended our knowledge of the subject, and to whom we owe the observation that a solid body placed between a pointed cathode and the walls of the tube cast a well defined shadow. This observation was extended by Goldstein, who found that a well marked, though not very sharply defined shadow was cast by a small body placed near a cathode of considerable area; this was a very important observation, for it showed that the rays casting the shadow came in a definite direction from the cathode. If the cathode were re-

* Discourse delivered at the Royal Institution, Friday evening, April 30th.

Sir Edward Victor Appleton

6 September 1892 – 21 April 1965

Nobel Prize in Physics 1947

Now we begin to see the “path” leading to AO. Appleton used what was basically a bistatic FM-CW radar to measure the height of the ionosphere. This was reported before the Brett & Tuve pulsed radar measurement although their measurements seem to have occurred first... His advisors were J. J. Thomson and Earnest Rutherford. His students included J. A. Ratcliffe.

Appleton, E. V., and M. A. F. Barnett (1925), On some direct evidence for downward atmospheric reflection of electric rays, *Proc. Royal Soc. Lond.*, *A109*, 621-641.

On Some Direct Evidence for Downward Atmospheric Reflection of Electric Rays.

By E. V. Appleton, M.A., D.Sc., Wheatstone Professor of Physics, King's College, London, and M. A. F. Barnett, M.Sc., Denman Baynes Research Student, Clare College, Cambridge.

(Communicated by Prof. Sir Joseph Larmor, F.R.S.—Received October 14, 1925.)

1. *Introduction.*

In a recent paper in these Proceedings (Series A, vol. 107, p. 587) Smith-Rose and Barfield have called attention to the two outstanding problems of the propagation of wireless waves over the earth's surface. A complete theory of wireless transmission must explain (*a*), why long-distance communication is possible, and (*b*), why large and rapid variations of signal intensity and apparent direction of propagation of the waves are observed at night, and, to some extent, during daylight, particularly in winter. Smith-Rose and Barfield further point out that both phenomena can be explained to some extent by the well-known Kennelly-Heaviside layer theory, but that it is generally admitted that further evidence of the existence of the layer is needed. They also describe accurate experiments designed to detect the existence of waves arriving at a wireless receiver in a downward direction (*i.e.*, inclined to the horizontal), such as must be present if the Heaviside layer theory is correct.

In these experiments Smith-Rose and Barfield sought, by directional methods, to detect a departure of the electric field of the waves from the vertical by means of a large Hertzian oscillator, and a departure of the magnetic field from the horizontal by means of a rotating frame aerial. It was, however, found that the conductivity of the ground was sufficiently high to make it act very nearly as a perfect reflector, and, because of the presence of the reflected wave from the ground, none of the effects sought for could be detected even in conditions such as are normally associated with signal strength and directional variations. These authors therefore concluded that the results of their experiments could not be considered as evidence for or against the Heaviside layer theory. In a later paper,* Smith-Rose and Barfield describe further experiments of this type, again with negative results, and state that "adequate experimental evidence on the existence of the Heaviside layer is still lacking."

* Smith-Rose and Barfield, 'Experimental Wireless,' September, 1925, p. 737.

Gregory Breit

July 14, 1899 – September 11, 1981

In 1925, while at the Carnegie Institution of Washington, Breit joined with Merle Tuve in using a pulsed radio transmitter to determine the height of the ionosphere, a technique important later in radar development. With faster publication they would have perhaps shared Appleton's Nobel Prize...

Merle Anthony Tuve

June 27, 1901 - May 20, 1982

Tuve was the founding director of the Johns Hopkins Applied Physics Lab.

Breit, G., and M. A. Tuve (1925), A radio method of estimating the height of the conducting layer, *Nature*, *116*, 357.

Hence there are two basic principles of patent law, (*a*) that patents are granted in consideration of the disclosure of inventions ; (*b*) that they are granted for the institution of new industries.

Although both principles may fitly be recognised in a given system of patent law, they cannot be regarded as coequal. For the type of administration appropriate to (*a*) not only differs from, but also is even antagonistic to, that which would naturally be evolved under (*b*). Under (*a*) there must be a highly elaborated machinery for the investigation of novelty, with the result that patents will be granted with relatively narrow claims, and that the capitalist be able to buy inventions cheaply, for patents will possess little restraining power. An official search, no doubt, gives additional security, but the commercially valuable factor in a monopoly is its restraining power. Hence, as a general rule, when security is at its highest the other factor will be " little, or none at all."

Trustworthy evidence of the commercial value of patents is not readily obtainable—for it is against the interest of patent officials, agents and owners alike publicly to depreciate their own services or properties. The following communication, however, was sent to the present writer in 1923 from a well-known scientific writer in Washington. He writes : " I have been wondering for some time whether the world's patent offices are not about to break down under their own weight. Simple arithmetic shows that the possible permutations and combinations of known principles and kinds of matter are so numerous that their task is hopeless unless the definition of invention or originality is radically changed. The U.S. Patent Office is already in a badly demoralised state and far behind with its applications, and its patents have for some years been recognised as worthless in themselves, being essentially only tickets of admission to the courts of law." Corroborative evidence on this point will be found in my letter to NATURE, Nov. 11, 1922, p. 633. These are inside views of the effect of a universal search upon the selling value of patents.

The writer of the articles in NATURE of July 25 and August 1 proposes a search through the 1759 periodicals taken in the Patent Office Library. But what about the 24,028 registered in the recently published "World List of Scientific Periodicals"? His search is to be limited to suit the convenience and capacities of the examining staff. Section 41 (1) of the Patents and Designs Act 1907 established the principle that "what we don't know isn't knowledge" in order to round off the official 50-year search (see my letter as above). When I pointed this clause out to a legal authority, he said it was "damned nonsense"—but it is proposed in the articles referred to above to extend the principle.

The remedy is obvious. An administrative search for novelty has long been an economic absurdity. The direction in which reform should be sought, if the object of our patent law is to stimulate the growth of British industries, is in the relief of the patentee from the unduly high legal standard of novelty. Sir John Dewrance in his presidential address before the Institution of Mechanical Engineers in 1923 supports this contention. He writes : " It has always seemed to me to be unfair that documents should be evidence of anticipation : evidence should be of prior use." This relief can, of course, be granted to the patentee only upon proof of commercial working.

Hence official search for novelty should be restricted to secure that concurrent British patents are not granted with overlapping claims. With a simplified procedure and broader claims, which can be substantiated so soon as the patented process has been reduced to practice, capital will once more flow into native industries.

Underlying the case presented in NATURE is the thesis that the public requires to be protected against the inventor. My case is that the inventor should be wooed and if possible won to come over and help us, and for this purpose I would make the law clear and consistent and the official practice cheap and expeditious.

E. WYNDHAM HULME.

A Radio Method of Estimating the Height of the Conducting Layer.

IN a recent note we have outlined a method of estimating the height of the conducting layer by means of radio waves (M. A. Tuve and G. Breit, *Terr. Mag.*, vol. 30 (1925), pp. 15-16). Through the co-operation of the U.S. Naval Research Laboratory, Bellevue, Anacostia, D.C., we have obtained definite indications of reflections such as would take place from the layer and some estimates of its height. The method used consists in sending out interrupted high frequency wave-trains and observing the wave-form of the received signal. Each wave-train received manifests itself as a temporary rise in the detector current of the receiving set. One particular wave-train at the transmitter gives rise to two received wave-trains at the receiver if a single reflection takes place. One of these trains travels over the ground and the other by way of the layer. Thus the detector current is forced to rise at two different times by the same wave-train from the transmitter and an oscillogram of the detector current shows two humps generally of unequal size.

The transmitter was operated with a 500-cycle plate current supply so that a wave-train of 71·3 metres wave-length was emitted during a part of each positive half of the cycle. A succession of single humps is thus emitted. (We have made sure of this by observing the wave form at the same time at the transmitting and the receiving stations.) The receiving station was located 7 miles away from the transmitter in a general direction north, the Potomac River and the City of Washington being between the two stations. We have observed the received wave-form visually and photographically. Double and triple humps were observed on some days, though practically single humps were observed on others. Marked variations in the relative position and amplitude of the humps were observed during 10-minute observation periods. The retardation of the secondary humps with respect to the primary is of the order of 1/1700 second, which corresponds to a retardation over a length of roughly 110 miles and a distance of the layer of the order of 50 miles. Other humps correspond to 100 miles. The origin of triple humps is not clear. The possibilities of a wavy surface in the layer and successive reflections suggest themselves.

Experiments on other wave-lengths with different receivers and transmitters and in different locations seem valuable. We are hoping that such experiments will be performed by others as well as ourselves. Some experiments at 600 metres were performed in co-operation with the Radio Corporation of America, the distances between the two stations being about 150 and 100 miles. No definite indication of the presence of the layer was found in these cases.

G. BREIT.
M. A. TUVE.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D.C.

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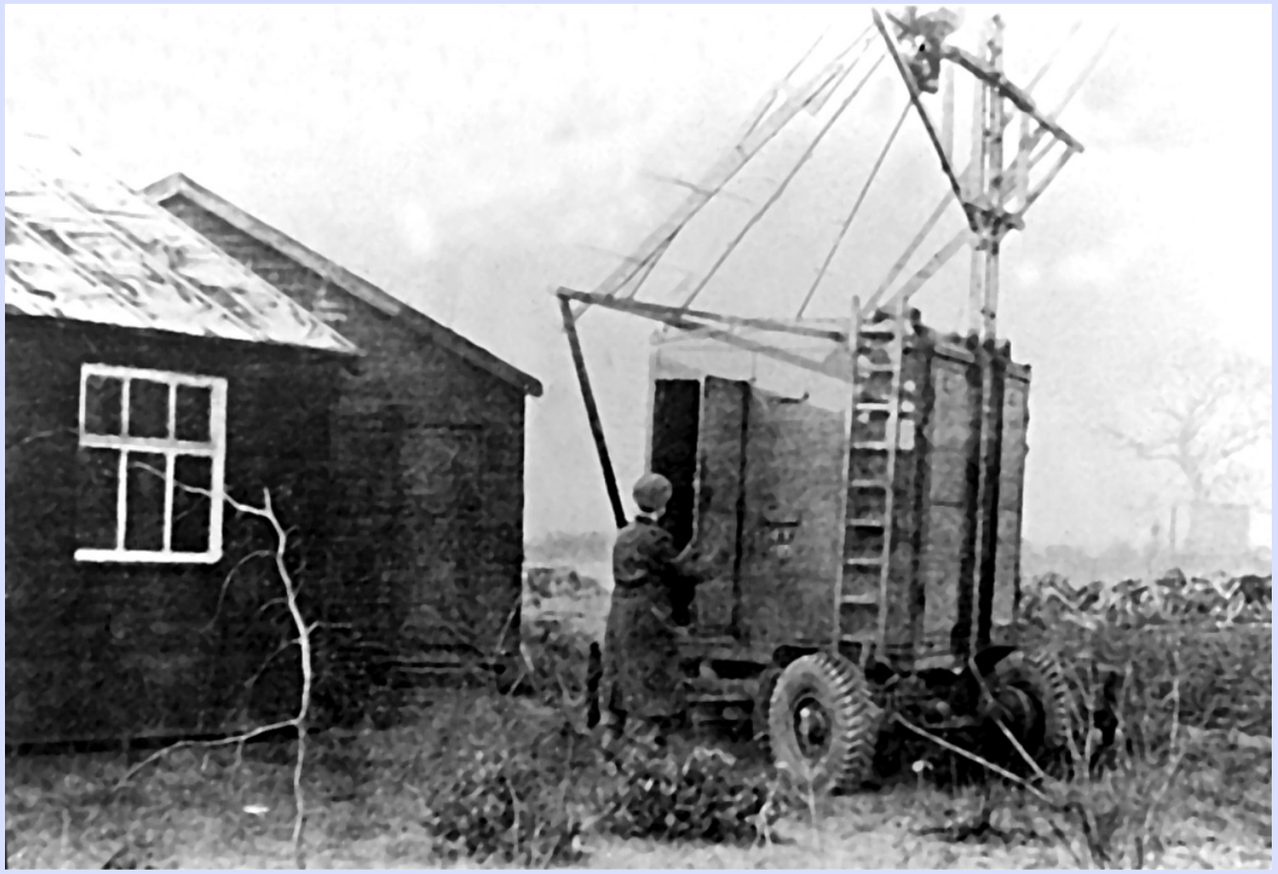
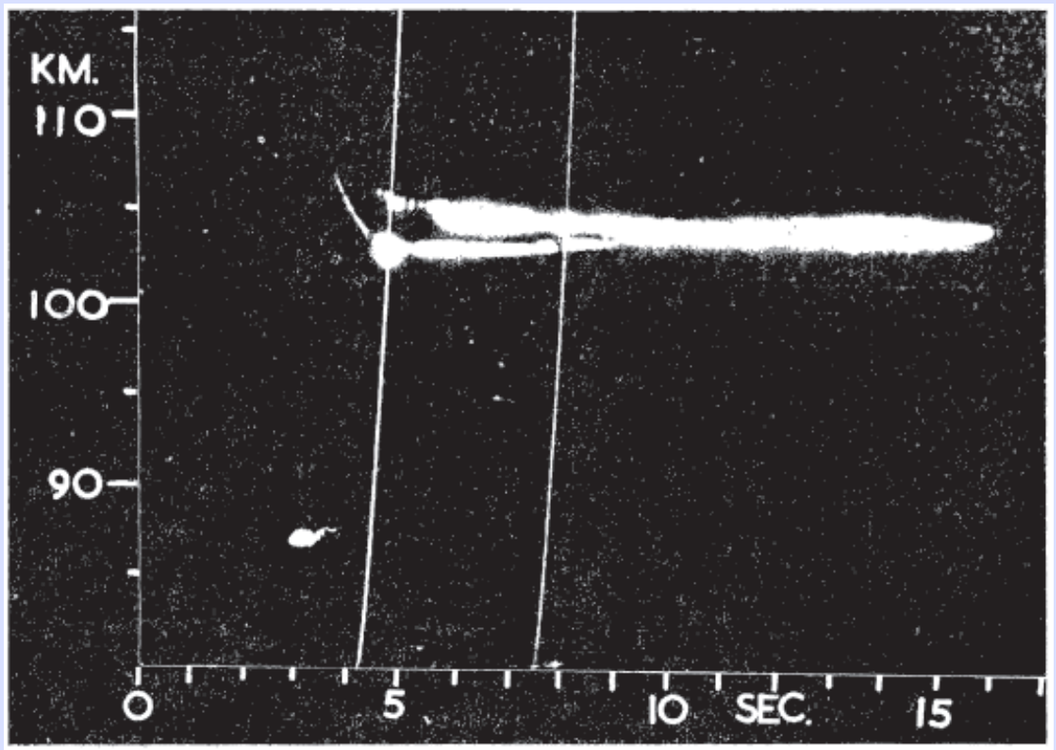
While there were significant developments in radio/radar in the 1930's—e.g., broadcast radio and the ionosonde came into use—oscilloscopes and rapid recording devices did not yet widely exist. WWII brought developments like the high power magnetron and various forms of rapid recording devices such as synchronous film recording of the radar Range-Time-Intensity results. Additionally, new vacuum tubes for receivers were developed and usable frequencies quickly moved into the GHz range with UHF technology becoming widely available. At the end of the war much of this equipment became available for science. For example, Sir Bernard Lovell founded the Jodrell Bank Experimental Station shown below in 1945 with a repurposed radar.





1946 October 10, 00h 55m U.T.

Plate 5 from Hey et al. (1947) similar to Plate 3 of Hey and Stewart (1947) showing a 55 MHz radar meteor displaying both a head-echo and an associated complex anomalous trail-echo. Note that the lower trail-echo likely corresponds to a terminal event. These Plates show the earliest published vertical-pointing, high-power VHF radar head-echoes in modern RTI format thus heralding "modern" meteor radar techniques.

Hey, J. S., and G. S. Stewart (1946), Derivation of meteor stream radiants by radio reflexion methods, *Nature*, *158*, 481-482.

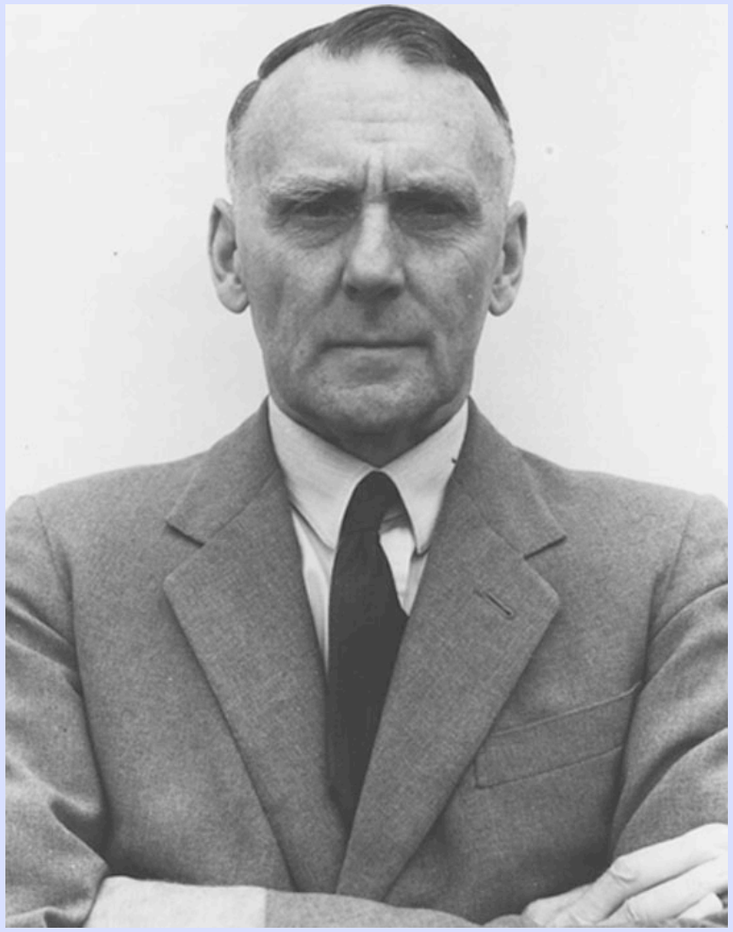
Hey, J. S., S. J. Parsons, and G. S. Stewart (1947), Radar observations of the Giacobinid meteor shower, *Mon. Not. R. Astron. Soc.*, *107*, 176-183.

Hey, J. S., and G. S. Stewart (1947), Radar observations of meteors, *Proc. Phys. Soc. Lond.*, *59*, 858-883, doi: 10.1088/0959-5309/59/5/312.

John Ashworth Ratcliffe

12 December 1902 – 25 October 1987

FRS

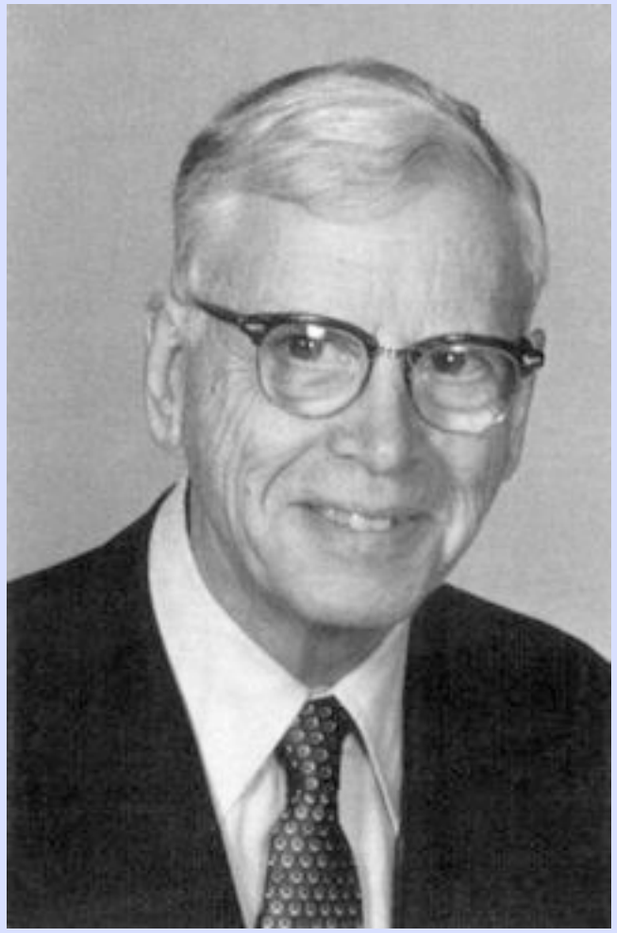


He and his University of Cambridge group did much pioneering work on the ionosphere, immediately prior to World War II. He was one of many leading radio scientists who worked at the Telecommunications Research Establishment during WWII. Martin Ryle, Bernard Lovell, and Antony Hewish were co-workers there, and Ryle and Hewish joined his radio-physics group at Cambridge after WWII. His students included David Whitehead, Ronald Bracewell, Henry G. Booker, Kenneth G. Budden, and Martin Ryle.

Henry G. Booker

14 *December 1910 — 1 November 1988*

Fellow IEEE, Member NAS



His PhD student and colleague, William E. (Bill) Gordon said of Henry—“Henry's research was elegant. That is not a word he would have used or that is used very often to describe research, but it fits. His work had beauty and style, and it was widely admired by those who understood it. He created ideas as a composer creates music or a sculptor creates art. All can be elegant. His teaching at Cornell was widely admired for its clear exposition, even of complicated subjects. Typical of his students' comments is that by Ken Bowles: ‘The best university level teacher that I ever experienced.’”

CC/NUMBER 6
FEBRUARY 8, 1982

This Week's Citation Classic

Booker H G & Gordon W E. A theory of radio scattering in the troposphere.
Proc. IRE 38:401-12, 1950.
[School of Electrical Engineering, Cornell University, Ithaca, NY]

The theory of scattering of radio waves by atmospheric turbulence in the troposphere shows that, at SHF, UHF, and VHF, the scattered field dominates the diffracted field at receivers located substantially beyond the horizon. This is the basis of tropospheric scatter communication. [The *SCI*® indicates that this paper has been cited over 120 times since 1961.]

Henry G. Booker
Department of Electrical Engineering and
Computer Sciences
University of California
La Jolla, CA 92093

November 2, 1981

"In 1949 it was known that, in the SHF, UHF, and VHF bands, the field received beyond the horizon often exceeds that due to diffraction and that, on many occasions, this is caused by atmospheric refraction. However, there were some observations that did not fit the refraction theory. The received field in these circumstances was Rayleigh distributed and suggested a scattering mechanism.

"In 1949, theories of scattering by atmospheric and oceanic irregularities existed for light and for sound. A theory of scattering also existed in wave mechanics, particularly the Born approximation. Moreover, under the direction of Jack Ratcliffe, a theory of radio scattering had just been developed at Cambridge for irregularities of ionization in the ionosphere.[1] When, at that time, I arrived at Cornell from Cambridge, William Gordon suggested that we apply these ideas to the troposphere. This paper is what emerged. One might perhaps imagine that Gordon was the professor and that I was a candidate for the PhD degree, but in fact the reverse was true.

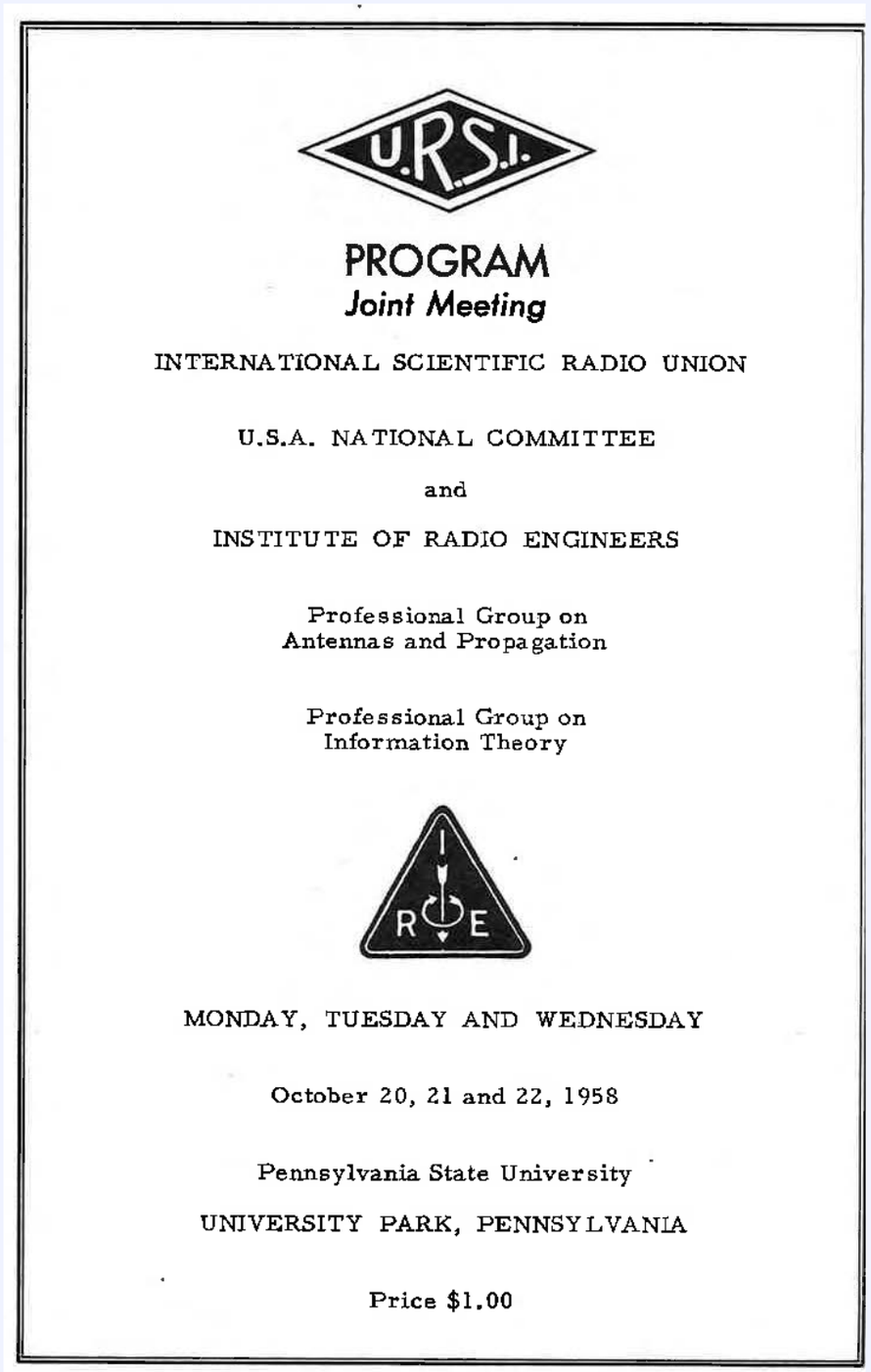
"In ionospheric scattering it was customary at that time to use a Gaussian autocorrelation function for the irregularities; this incorrect notion persisted in ionospheric scattering for many years thereafter, and for an even longer period in radio astronomy. It was again Gordon who realized in 1949 that, at least for the troposphere, the exponential autocorrelation function is much closer to the truth. It was the switch from the Gaussian autocorrelation function to the exponential autocorrelation function that made possible the scattering explanation of what came to be known as tropospheric scatter communication.

"The paper almost certainly played a timely role in the development of tropospheric scatter communication. Applied to the E region of the ionosphere, it also played a timely role in the development of ionospheric scatter communication.[2] Applied to missile wakes, it played a role in identifying the cause of enhanced radar echoes. Applied to irregularities in the ionospheric F region aligned along the Earth's magnetic field, it has contributed to our understanding of 'spread F.'[3] Even recently, this development of the theory has been used to generate a quantitative treatment of transequatorial propagation at VHF.[4]

"The basic theory presented in 1950 has stood the test of time reasonably well. However, the exponential autocorrelation function, while vastly superior to the Gaussian autocorrelation function, has needed some modification to bring it into agreement with the Kolmogoroff spectrum of turbulence. On the other hand, the numerical values used in 1950 have not stood the test of time. No inner scale of turbulence was then used; it is not important for tropospheric scattering, but it is needed for ionospheric scattering. The scale used in 1950 was in fact the outer scale of turbulence. Its magnitude was grossly underestimated, as also was the mean square fluctuation of the refractive index. The two errors roughly balanced because it is only a combination of the two parameters that is actually important."

1. **Booker H G, Ratcliffe J A & Shinn D H.** Diffraction from an irregular screen with applications to ionospheric problems. *Phil. Trans. Roy. Soc. London A* 242:579-609, 1950.
2. **Bailey D K, Bateman R, Berkner L V, Booker H G, Montgomery G F, Purcell E M, Salisbury W W & Wiesner J B.** A new kind of radio propagation at very high frequencies observable over long distances. *Phys. Rev.* 86:141-5, 1952.
3. **Booker H G & Ferguson J A.** A theoretical model for ionospheric spread F echoes in the HF and VHF bands. *J. Atmos. Terr. Phys.* 40:803-29, 1978.
4. **Ferguson J A.** *A scattering theory of transequatorial propagation at VHF.* PhD dissertation. La Jolla, CA: University of California, 1982.

William E. Gordon and William McGuire working with a late 1958 model of the Arecibo radar dish and feed system. Note that the original feed system envisioned was simply a 500-foot tower at the center of the parabolic dish. Professor McGuire was on the faculty of the Cornell Department of Civil Engineering and was involved in the structural design and in the maintenance of the Arecibo dish and platform structural infrastructure for many decades. (Photo courtesy of Cornell University and Prof. D. B. Campbell.)



4. INCOHERENT SCATTERING OF RADIO WAVES BY FREE ELECTRONS WITH APPLICATIONS TO SPACE EXPLORATION BY RADAR--W. E. Gordon, Cornell University, Ithaca, New York--Free electrons in an ionized medium scatter radio waves weakly. Under certain conditions only incoherent scattering exists. A powerful radar can detect the incoherent backscatter from the free electrons in and above the earth's ionosphere. The received signal is spread in frequency by the Doppler shifts associated with the thermal motion of the electrons.

On the basis of incoherent backscatter by free electrons a powerful radar, but one whose components are presently within the state of the art, is capable of

(1) measuring electron density and electron temperature as a function of height and time at all levels in the earth's ionosphere and to heights of one or more earth's radii;

(2) measuring auroral ionization;

(3) detecting transient streams of charged particles coming from outer space; and

(4) exploring the existence of a ring current.

The instrument is capable of

(1) obtaining radar echoes from the sun, Venus, and Mars and possibly from Jupiter and Mercury; and

(2) receiving from certain parts of remote space hitherto-undetected sources of radiation at meter wavelengths.

THE URSI meeting at Penn State where Bill Gordon announced both the concept of incoherent scattering and its detection by Ken Bowles.

USA NATIONAL COMMITTEE, URSI

Minutes of October 20, 1958 meetings
Pennsylvania State University
University Park, Pennsylvania

The first meeting was called to order by Chairman W. E. Gordon at 9:30 a.m. October 20 in Room 111, Electrical Engineering Building; the second meeting at 5:00 p.m. in the same place.

The following members were present at one or both sessions:

W. E. Gordon, Chm.
E. W. Allen
J. I. Bohnert
W. Q. Crichlow
J. H. Dellinger
F. H. Dickson
H. E. Dinger
I. H. Gerks
R. A. Helliwell
G. D. Lukes
L. A. Manning
E. F. McClain
M. G. Morgan
A. H. Schooley
A. H. Shapley
Samuel Silver
R. J. Slutz
J. B. Smyth
A. H. Waynick

Others present were: D . W. W. Atwood, Jr., Director, Office of International Relations, National Academy of Sciences-National Research Council, Mrs. A. MacIntyre.

The following members were not present: S. L. Bailey, R. W. Beatty, L. V. Berkner, H. H. Beverage, Marvin Chodorow, R. G. Fellers, H. W. Grant, F. T. Haddock, J. P. Hagen, A G. Jensen, E. C. Jordan, J. E. Keto, K. A. Norton, Brian O'Brien, J. D. O'Connell, W. G. Shepherd, L. C. Van Atta, Frank Virden, Ernst Weber, H. W. Wells.

Agenda Item 1. Minutes of April 25, 1958 meeting

The minutes were approved as mailed out with modification as follows: On page 3, lines 13 to 15, "President" should be "Chairman". On page 10, an item should be inserted between paragraphs numbered 2 and 3: "The list of officers should include the Associate Editor of Information Bulletin."

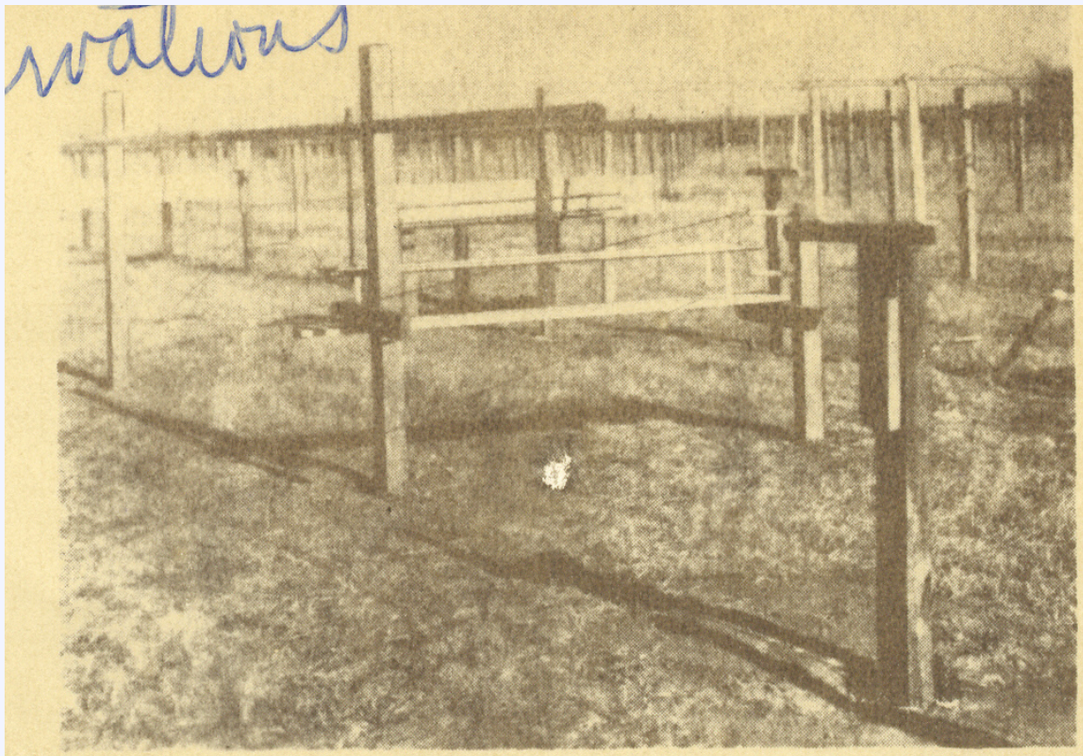
Agenda Item 2. Report of the Secretary

Dr. Silver expressed satisfaction with the functioning of the D. C. office.

Dr. Atwood outlined the present responsibility of the Academy with respect to the office of the USA National Committee in Washington and stated that at the earliest practicable date the Academy would take over the full responsibility of providing Secretariat services which the Committee needs. The plan is that the office of the USA National Committee will be incorporated into the Office of International Relations in cooperation with the Division of Physical Sciences. This is for several reasons:

(1) If OIR is to be of greatest help to a Union, its experience with the others should be readily available and this may be best accomplished if the work of all the Unions is handled under one office. However, Dr. Atwood recognized that the USA National Committee's meetings twice a year impose a larger work load than the other Unions.

(over)



Individual dipoles, part of 4-acre array autenna at Long Branch, Ill. This antenna, consisting of 1,024 dipoles, will be used to study the physics of the upper reaches of the ionosphere.

While Gordon was refining the Arecibo designs, he was famously in contact with Dr. Kenneth Bowles, a recent Cornell PhD, then at the National Bureau of Standards (NBS) in Boulder, Colorado. Bowles had access to an NBS 41 MHz forward-scatter transmitter/antenna system located near Long Branch (Havana) Illinois. All he needed was a suitable zenith-looking antenna system of sufficient gain and capability to handle the 4–6 MW peak power. The 116m × 140m half-wave dipole array (1024 elements) was quickly built by a tree surgeon from Ithaca, New York and the experiment to test for incoherent scattering was conducted with positive results (Bowles, 1958).

the single-crystal sample.

The broad lithium line in the single crystal has a separation of maximum slopes of 24 kc/sec for an orientation with the constant magnetic field along a [100] direction. This is larger than the value 20.6 kc/sec calculated from Van Vleck's equations.[3] Interactions of the Li^7 nuclear electrical quadrupole moments with field gradients arising from defects in the irradiated crystal may be responsible for this broadening.

These findings are in agreement with x-ray studies of neutron-irradiated LiF. Smallman and Willis[5] have concluded from their analysis that aggregates of fluorine atoms are trapped within the crystal. Lambert and Guinier[6] have concluded from small-angle scattering analysis that lithium atoms are present in the form of platelets parallel to the (100) planes. Thus the narrow Li^7 and F^{19} lines may be due to colloidal lithium metal and molecular fluorine gas.

Further studies of the lithium and halogen resonances, as functions of radiation dosage and post-irradiation annealing, are in progress on both single crystals and powders of LiF and other lithium halides. Quantitative determinations of the amount of damage and the behavior of the displaced metal and halide ions are now possible.

†Research supported by the U. S. Atomic Energy Commission.

[1]A cylindrical sample 1/2 in. long and 7/16 in. in diameter purchased from the Harshaw Chemical Company.

[2]H. S. Gutowsky and C. J. Hoffman, J. Chem. Phys. 19, 1259 (1951).

[3]J. H. Van Vleck, Phys. Rev. 74, 1168 (1948).

[4]W. D. Knight, Solid State Physics (Academic Press Inc., New York, 1956), Vol. 2, p. 93.

[5]R. E. Smallman and B. T. M. Willis, Phil. Mag. 2, 1018 (1957).

[6]M. Lambert and A. Guinier, Compt. rend. 245, 526 (1957).

OBSERVATION OF VERTICAL-INCIDENCE SCATTER FROM THE IONOSPHERE AT 41 Mc/sec

K. L. Bowles
Central Radio Propagation Laboratory,
National Bureau of Standards,
Boulder, Colorado
(Received November 12, 1958)

The possibility that incoherent scattering from free electrons in the ionosphere, vibrating independently, might be observed by radar techniques has apparently been considered by many workers although seldom seriously, because of the enormous sensitivity required. Recently Gordon recalled this possibility to the writer while remarking that he hoped soon to have a radar sensitive enough to observe incoherent electron scatter in addition to various astronomical objects.[1] Subsequent calculations indicated that a new 41-Mc/sec pulse transmitter, due to be received by the National Bureau of Standards, should permit observation of the incoherent electron scatter if a relatively simple antenna of large cross section were constructed.

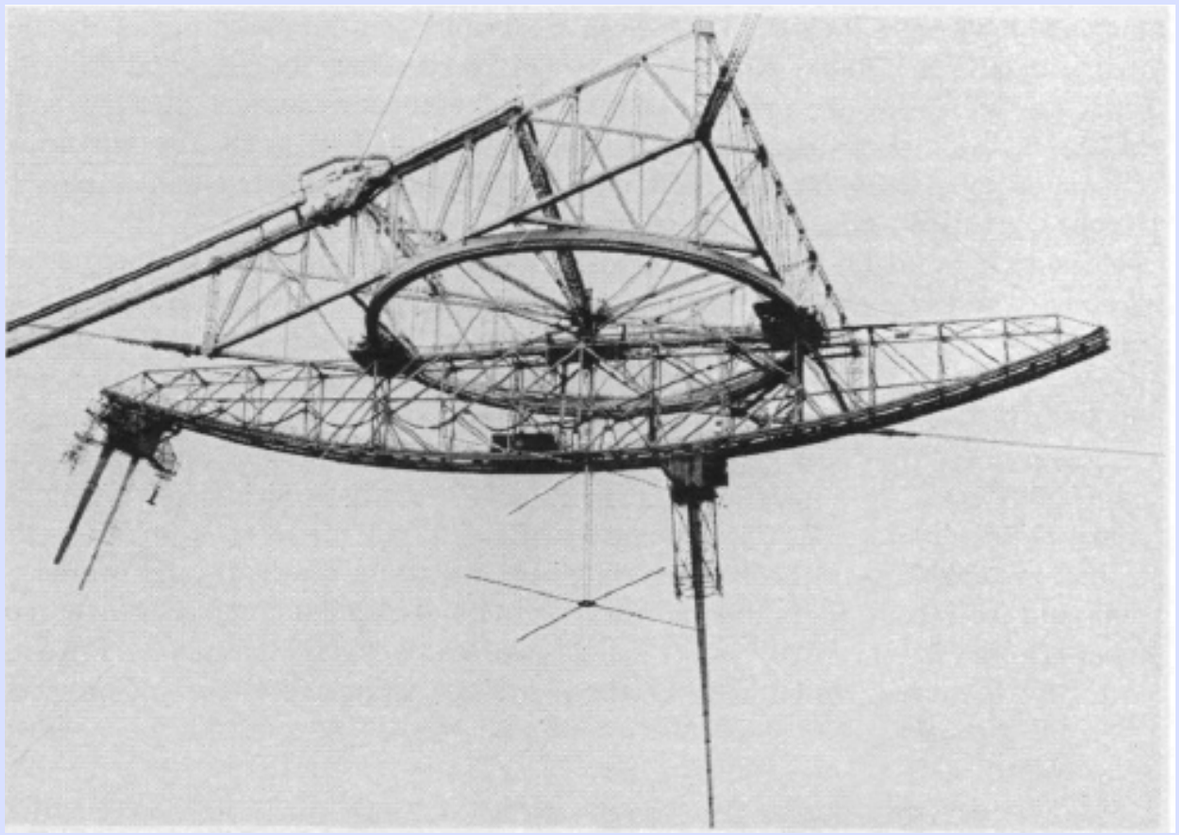
The phenomenon of incoherent scattering of electromagnetic radiation by gas molecules has been recognized for many years at optical wavelengths.[2] The suggestion of observing electron scatter at radio wavelengths is a consequence of the relatively large radar cross section of electrons, compared with atoms or molecules. The optical observations have confirmed that the average distance between the scattering particles determines whether the particles may be considered to scatter independently. When they do scatter independently, the scattered power is proportional to the number of particles present. When observing a volume deep in wavelengths containing many particles having a mutual spacing shallow in wavelengths, the particles can no longer be considered to scatter independently. However, statistical fluctuations of the density of particles on a scale comparable to a wavelength gives rise to a different form of scattering, which turns out to be only slightly weaker than the completely independent scatter.[3] Optical experiments have apparently been somewhat inconclusive as to the exact criterion for close versus loose packing and the manner in which the scatter behaves in the transition region. One significant difference between the two kinds of scatter is apparent – that of frequency broadening of the scattering wave. The completely incoherent scatter should be heavily broadened due to Doppler shifting of the component scattered waves by thermal motions of the scatterers. The semi-incoherent scatter, mentioned above, will be broadened only slightly due to thermal fluctuations.[3] In both cases, radar observation of the scatter should provide a means of determining directly the electron density versus height profile of the ionosphere.

The brief observations reported herein were undertaken in an attempt to verify the existence

Now to some of the radars and HF heater systems at or near to AO.

The first functioning radar feed at AIO. This 430MHz hornfeed was constructed to test the full radar system before the dish was completed. This feed had a ~10 degree half-power beamwidth and was in operation in mid-October 1962. It was used to receive the sun in transit and to obtain lunar echoes as the moon transited near zenith (Gordon, 1962a). Photo courtesy of Carmen G. Segarra-Saavedra (Segarra-Saavedra, 2012).

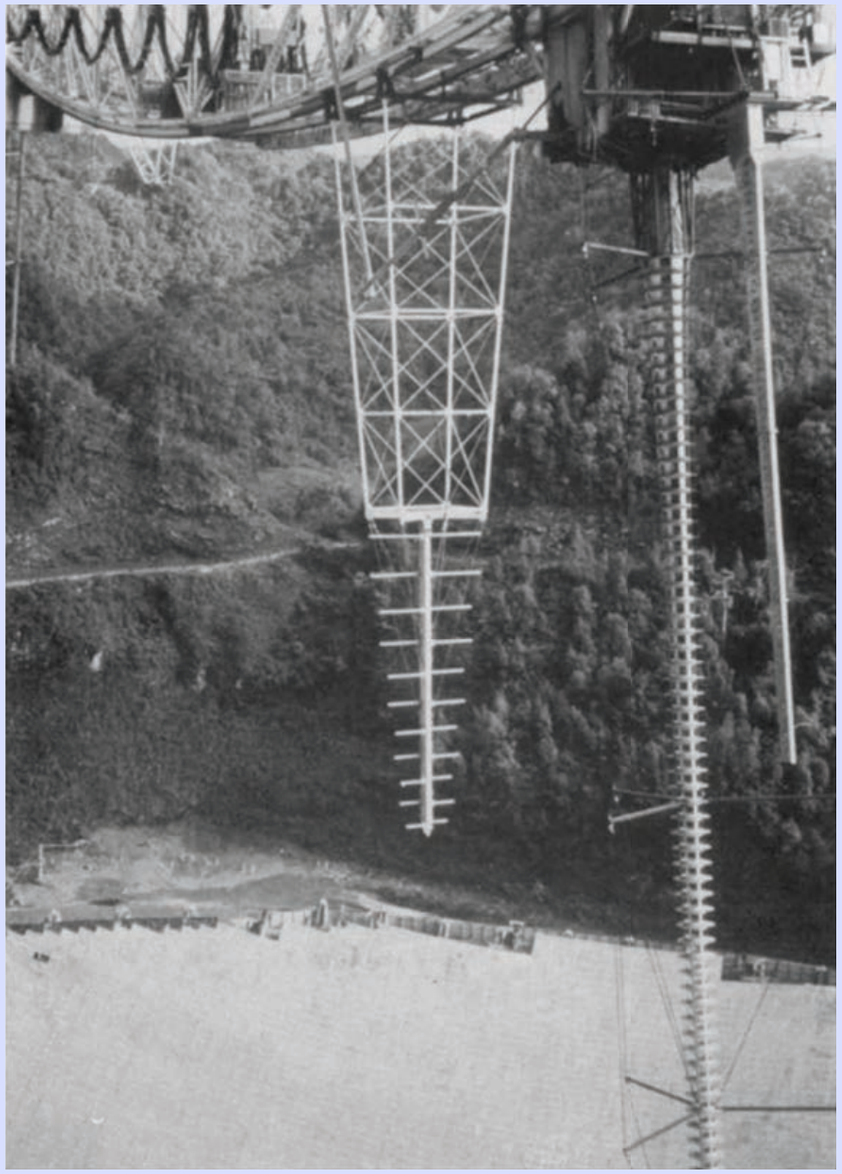
A picture from 13 May 1971 showing the carriage house with the 40MHz radar feed system consisting of four Yagi antennas placed symmetrically around the original square cross-section 430MHz linefeed. Note the cable car giving convenient access to the platform relative to the catwalk which is located to the right and above the cable car in this photo. Photo courtesy of Cornell University and Arecibo Observatory.



Antenna feeds deployed over the AO dish circa 1970. The crossed-dipole feed with reflector elements at center of the elevation arc is the first HF (5.62 MHz) heating antenna. L. M. LaLonde designed and built this feed. Carriage house #1 to the right of center supports the original square cross-section 430 MHz linefeed and the coaxial 40.12 MHz radar Yagi feeds. Carriage house #2, now replaced with the Gregorian dome system, shows a variety of radio astronomy feeds. Photo courtesy of D. B. Campbell and Cornell University.

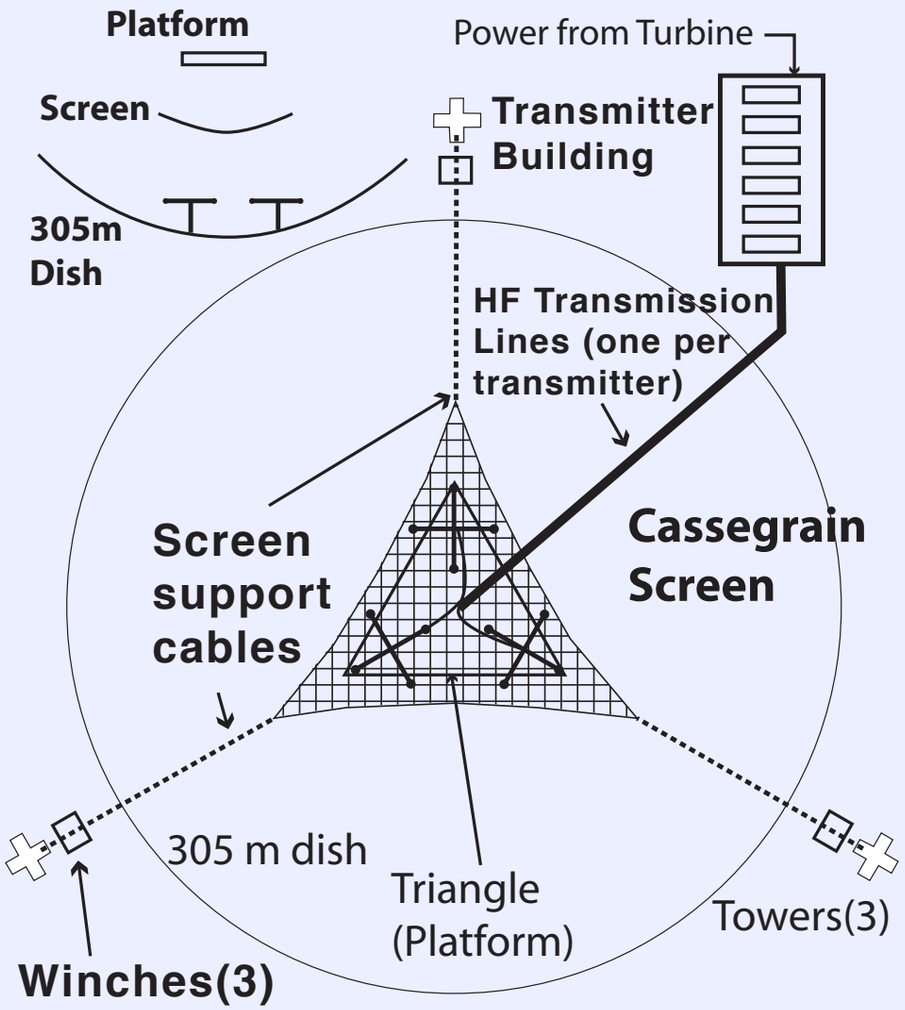
The Arecibo Observatory feeds in July 1972. The new 430 MHz linefeed is mounted on carriage house #1 to the right in this photo. In the center is the HF log-periodic feed for ionospheric heating experiments. To the left is carriage house #2 with various radio astronomy feeds including those at 318 MHz (left, 40 feet long), 611 MHz (right, 45 feet long), the far-right feed is likely 1667 MHz test feed while the feeds at the far left are likely nested Yagis at 111 MHz and 196 MHz (D. B. Campbell, personal communication, 2013). Note the catwalk at the upper left of the photo. Photo courtesy of Cornell University and Arecibo Observatory.

The Islote heater facility circa 1997. In these aerial views most of the two 4 × 4 log periodic antenna arrays is visible with the transmitter/control building to the left top and the ocean just visible at the top right. The dual, closed coaxial “cable” (constructed from irrigation pipe) transmission line system to the center of each log periodic feed is clearly visible as are the support towers. The wire log periodic feeds are not visible but are suspended from four towers with two linear polarizations each driven from a separate transmission line. Photo courtesy of Cornell University and Arecibo Observatory.



The Max Planck Institute for Aeronomy 46.8 MHz SOUSY radar feed mounted downhill from carriage house 1 (CH1) and towed by CH1. This was an 11-element log-periodic antenna with 45–55 MHz frequency range and an 8 dB gain, yielding 60 degree half-power beamwidth to efficiently illuminate the dish. The 430 MHz radar line feed and 318 MHz radio astronomy feed are mounted on the carriage house (Röttger et al., 1981).

The modern 430 MHz linefeed and coaxial 46.8 MHz dual-polarization Yagi feeds as of August 2012. The 46.8 MHz feed is comprised of four, 3-element Yagi antennas and yields ~1.4 degree fullwidth at half-maximum beamwidth and ~40 dBi gain (Mathews et al., 2010). Photo by author.



Arriving at 2013...

Schematic cartoon of the new AO on-dish heating facility. The upper left schematic shows the side-view with dipoles just above the dish surface and the convex sub-reflector mounted below the platform. The top view shows the wide-mesh Cassegrain sub-reflector and three of the six crossed-dipoles. The transmission lines are ~1000 ft in length. Figure courtesy of M. P. Sulzer, Arecibo Observatory.

The first of six crossed-dipole HF feeds to be deployed on the Arecibo Observatory 305 m dish. These feeds will illuminate a wire sub-reflector to be suspended from the towers that will in turn illuminate the dish. Three feeds are sized for 5.1 MHz (λ = 58.8 m) and three feeds for 8.175 MHz (λ = 36.7 m). Modeling of the configuration suggests 22.2 dBi one-way gain at 5.1 MHz (~12° FWHM beamwidth) and 25.5 dBi gain at 8.175 MHz (~8° FWHM beamwidth). As six 100 kW CW transmitters are available, each polarization of each of the three feeds at a single frequency will be separately driven permitting full polarization flexibility. The transmitters are class-A however pseudo-pulsed operation will be possible. Later operations at 3.175 MHz may become possible. Photo 21 July 2013, JDM.

Where Next?

The Role of Arecibo Observatory in 21st Century Graduate and Post-Graduate Education

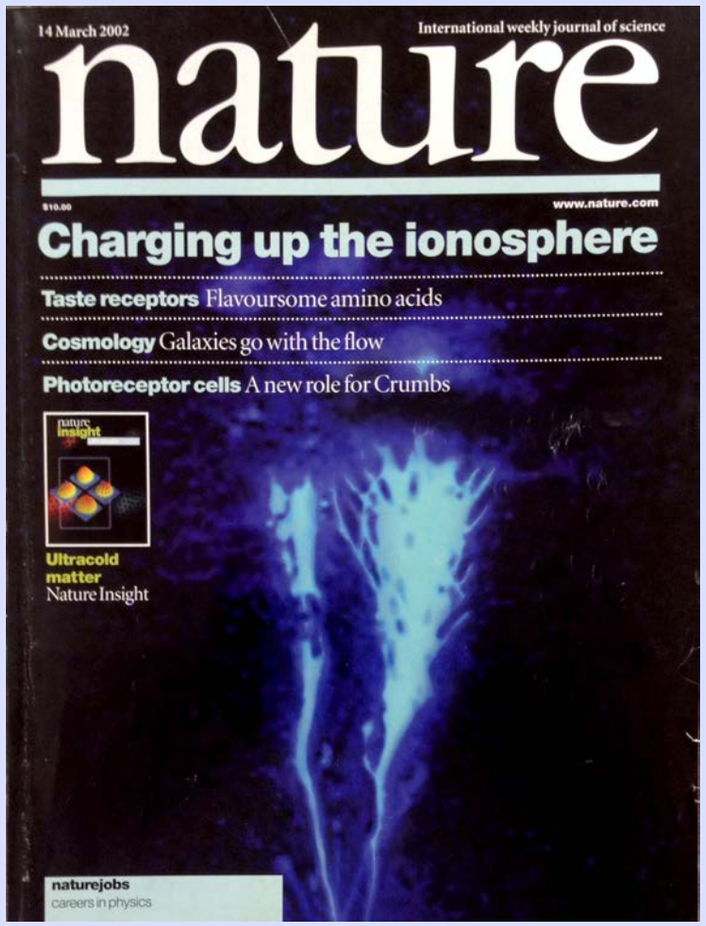
Arecibo Observatory has always presented a remarkable mix of education and research without placing artificial boundaries between the various disciplines represented in its day-to-day functioning. The fruits of this multidisciplinary and interdisciplinary environment are found in the generations of AO "graduates" and in the hundreds of important scientific and engineering advances developed here. As university education must evolve beyond its centuries-old models and embrace the realities and opportunities of the 21st century, AO is presented with an opportunity to be a leader of this revolution. What is needed? Formalization of what AO has always done—with this well-articulated set of goals, sufficient financing can be found.

- Global scale cutting-edge research & cutting-edge graduate and post-graduate education cannot be separated—new management and fiscal paradigms must be discovered.
- Faculty and students not only can but must be distributed around the world—a globalized mechanism for assembling "critical-mass" research groups.
- AO will be at the focus of a multi-disciplinary graduate degree awarding entity.
- AO will continue doing cutting-edge research both locally and as part of team science with collaborating institutions. Globalization and entrepreneurship are here—multi-institution, multi-discipline degrees will be awarded.

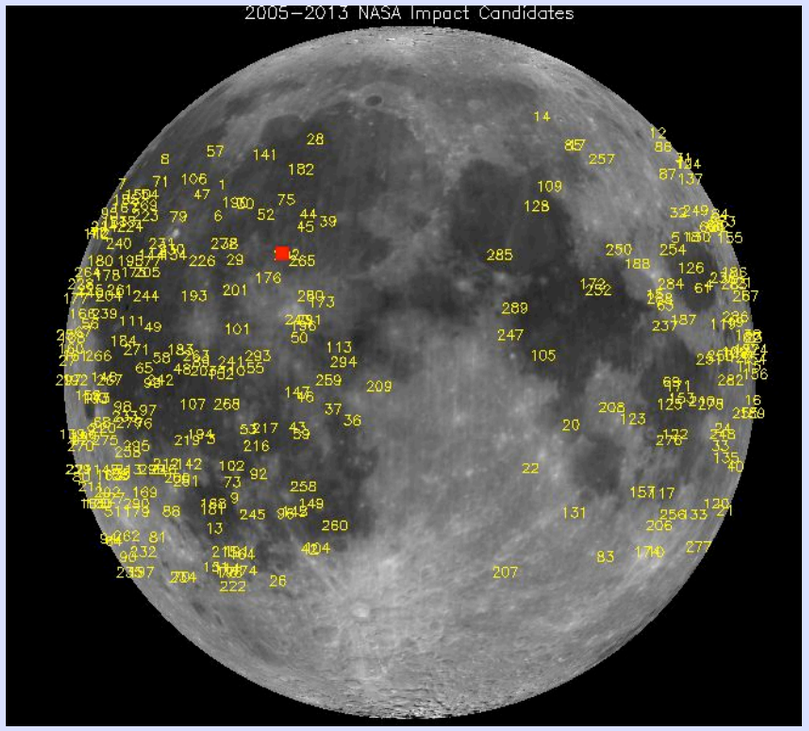
AO science in the next 20 years.

- For AO science—and thus engineering and educational initiatives—to continue, the physical environment surrounding AO must be protected for new infrastructure such as array antennas and to provide a buffer against RF and light pollution.
- Critically, a major planning effort to widely protect the RF spectrum and the night sky.
- In the space and atmospheric sciences, as in radio astronomy, transient event studies will become more important. See below.
- ASAP sponsored Blue-Sky discussion this afternoon!

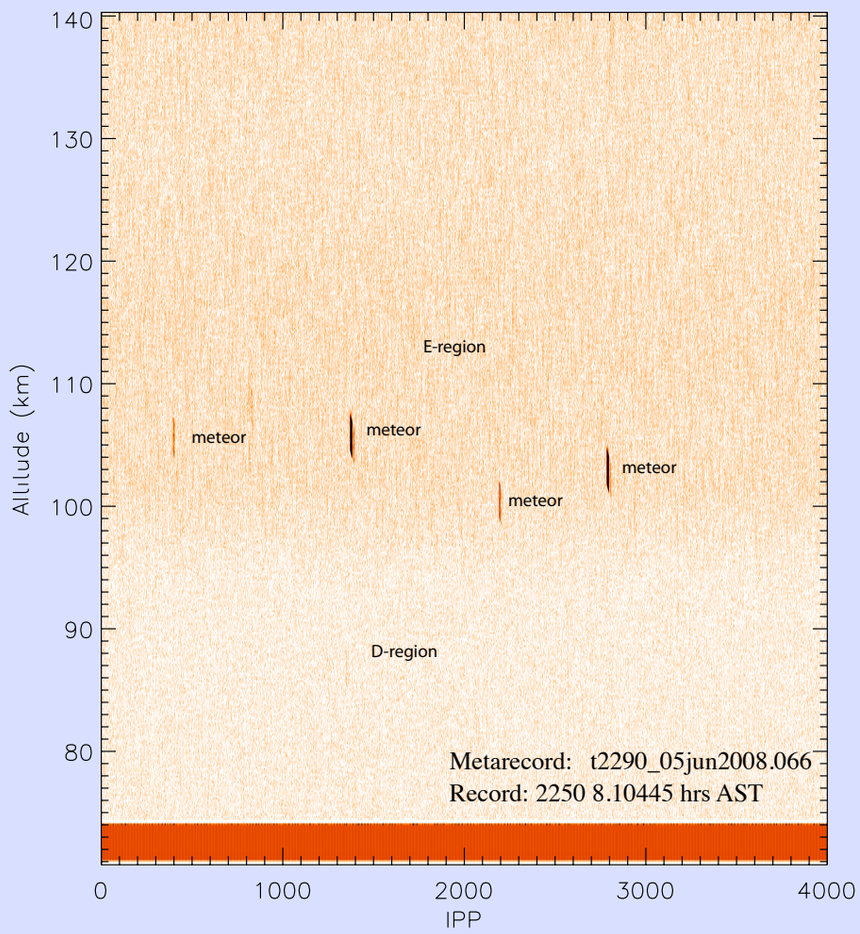
Gigantic Jet (TLE) observed from AO.
Needs: radars, cameras, magnetometer.



Lunar meteoroid impact flashes and EMPs.
Needs: AO, Haystack, GBT simultaneous observations.



Elemental incoherent scattering and meteors observed from AO. Needs: multiple VHF/UHF common-volume radars.



Please consider joining ASAP!
Thanks!

Author Bio

J. D. Mathews joined Penn State as Professor of Electrical Engineering in 1987. He received all of his degrees from Case Institute of Technology and Case Western Reserve University (PhD, 1972, Electrical Engineering & Applied Physics) where he was professor from 1975 through 1987. His research interests have included ionospheric electrodynamics, instabilities, and layering processes. His current research involves radar meteor studies including the radio science of radar meteors, aeronomy of the meteoroid mass flux, orbital determination and evolution, and the origins of interplanetary and interstellar particles. He also is also involved in system-of-systems autonomous sensor systems, radar signal processing, and novel signal processing systems. He has continuously conducted research at Arecibo Observatory (AO) since 1969 and has held NSF grants for observational research at AO and other major radar facilities since 1975. He is a member of the American Geophysical Union, URSI (International Union of Radio Sciences) Commissions G and H where he is currently the international Commission G chair, IEEE (Fellow), European Geosciences Union, the Division for Planetary Sciences of the American Astronomical Society, and the Royal Astronomical Society (Fellow).